ADR Cooling for IR Telescopes and Detectors

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Session B
Cooling Systems for Large Telescopes
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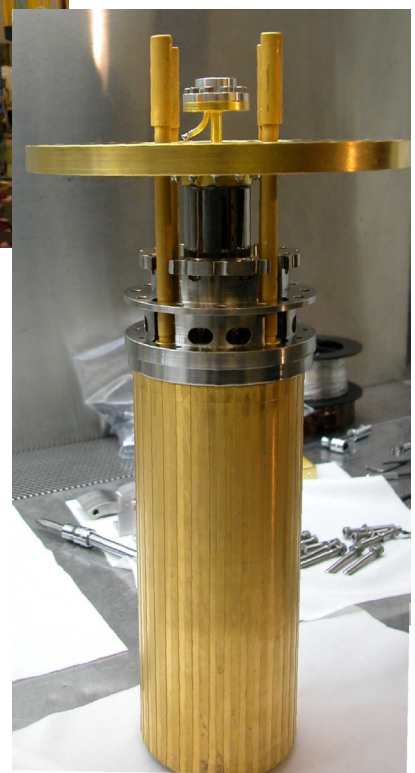
Introduction

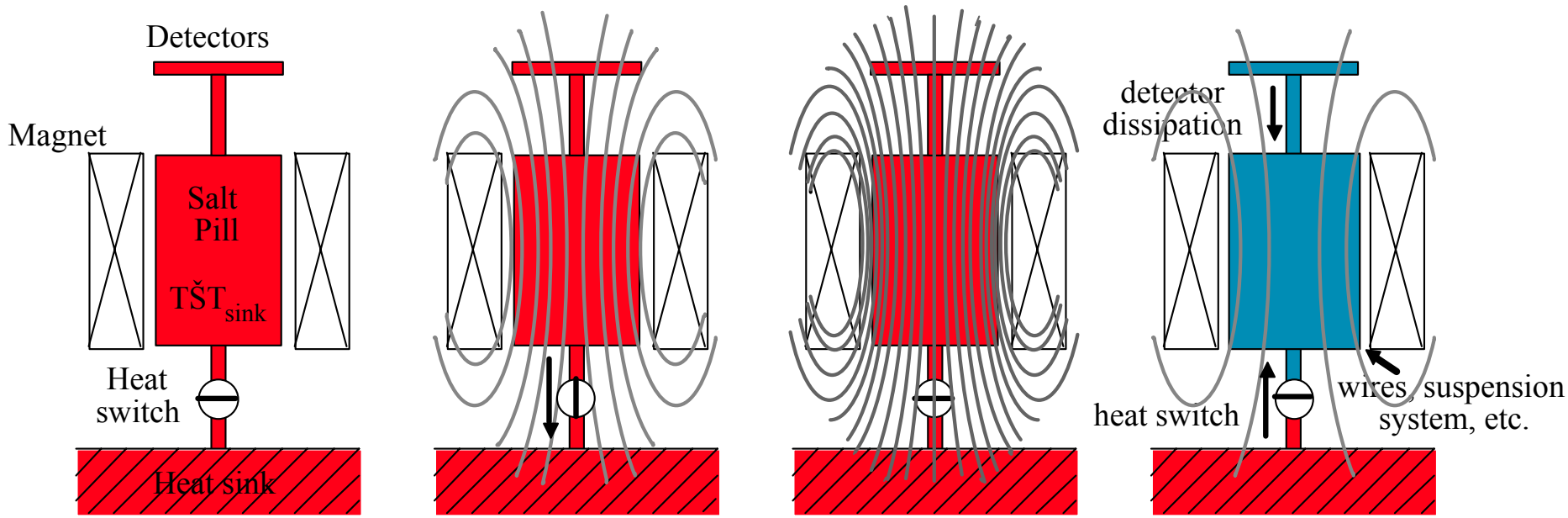
- ***Future Needs***
  - ***Detector Cooling***
    - ***Up to 10 μW at 50 mK***
    - ***Cooling to 20 mK***
  - ***Cooling for Large Telescopes***
    - ***10-100 mW at 4 K***
  - ***Cryogen-free, high efficiency***

- ***ADR Development***
  - ***Primarily for low temperature detector cooling***
    - ***First flight ADR will launch on Astro-E2 Feb. 2005***
  - ***Multi-stage configuration makes operation to 30+ K possible***
  - ***Talk emphasizes***
    - ***Configurations for low, intermediate and high T***
    - ***Technology development needed***



ADR Cycle (Carnot)

Recycling | **Operational Mode**



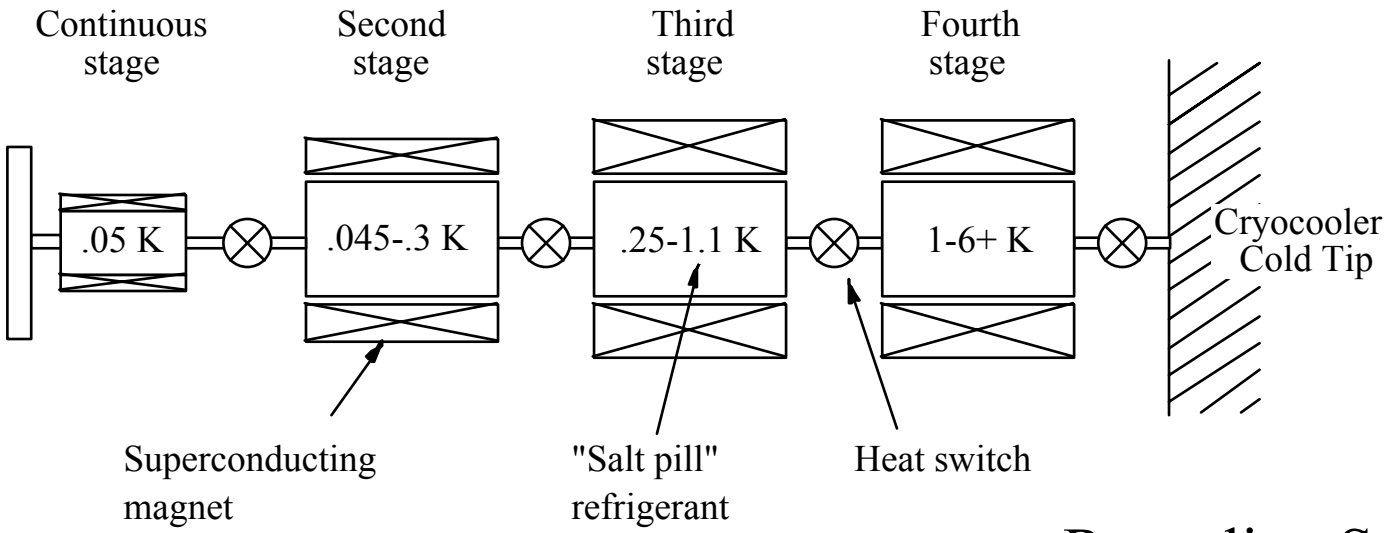
- *B=0*
- *$T_{salt} \leq T_{sink}$*

- *Magnetize salt until $T_{salt} \geq T_{sink}$*
- *Turn on heat switch*

- *Magnetize to full field*
- *Wait until $T_{salt} \sim T_{sink}$*
- *Turn off heat switch*

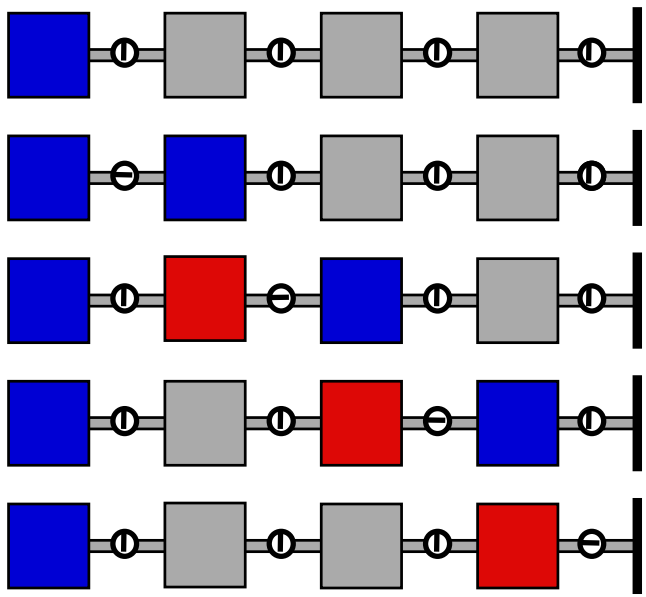
- *Demagnetize until T_{salt} reaches operating point*
- *Slowly demagnetize to maintain stable T as salt absorbs heat*

Continuous ADR



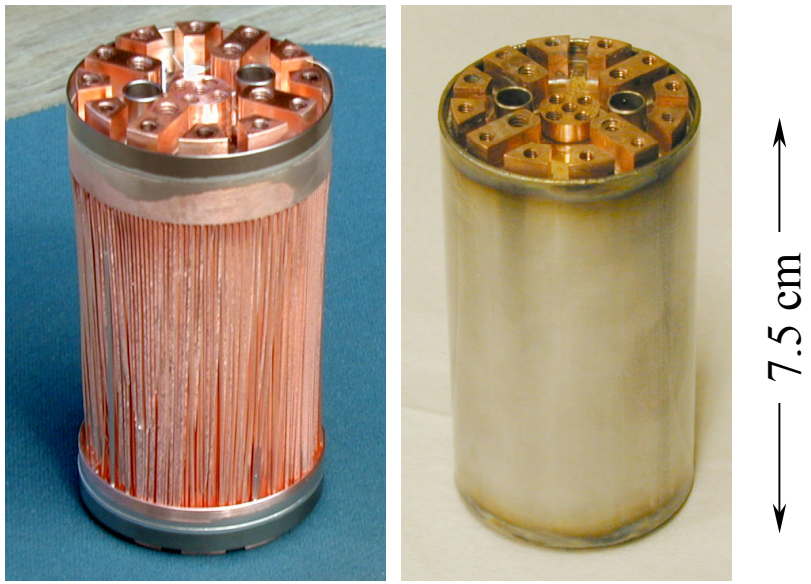
- ***Load is cooled by a "continuous" stage***
- ***Stages 2-4 cascade heat to the heat sink***
- ***Benefits***
  - ***Solid state, no moving parts, no gravity dep.***
  - ***Continuous cooling***
  - ***1-2 orders of magnitude higher cooling power per unit mass***
  - ***Scalable to higher cooling power***
  - ***Expandable to higher heat sink temperature***

Recycling Sequence



Salt Pills/Refrigerants

- ***Low temperature refrigerants***
  - ***Hydrated salts***
  - ***Thermal bus occupies ~25% of salt pill volume***
  - ***Very high thermal conductance even at low temperature***

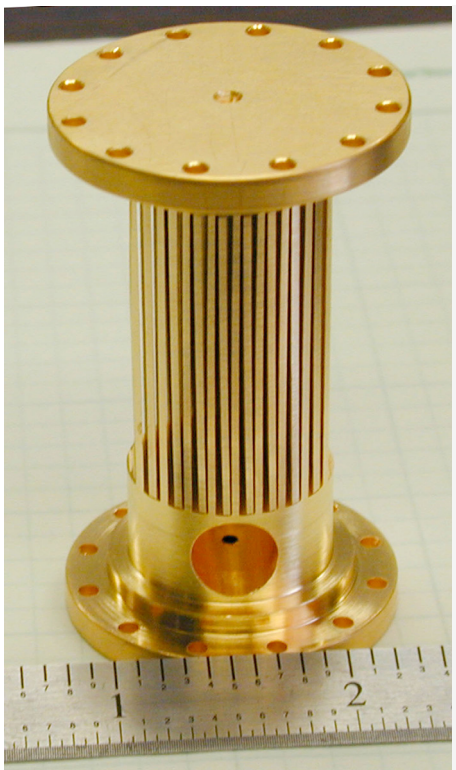


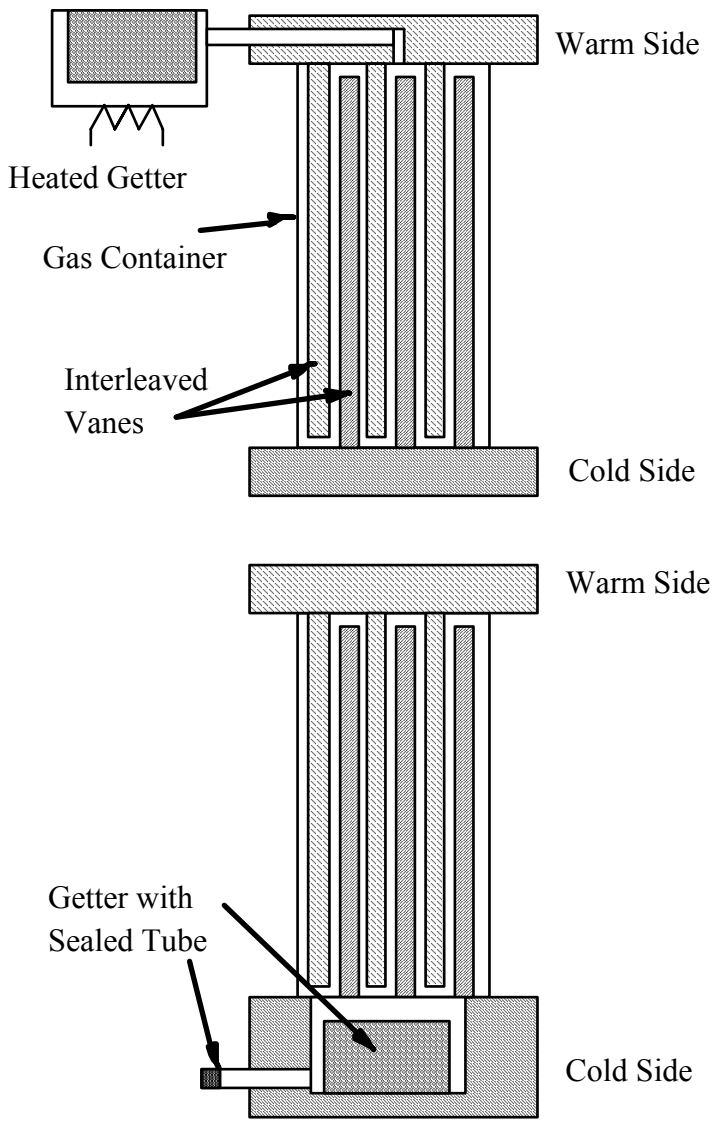
Salt Pill
(100 gram CPA)

- ***High temperature refrigerants***
  - ***Single or poly-crystal***
  - ***GGG, $GdLiF_4$, GdF_3, …***
  - ***Transition temperatures of .5-2 K***

Passive Gas-Gap HSs

- ***Traditional GGHS Has Separate Getter Attached to Warm End of Switch***
- ***Passive GGHS Has Getter Housed Within Switch at Cold End (For ADR Use)***

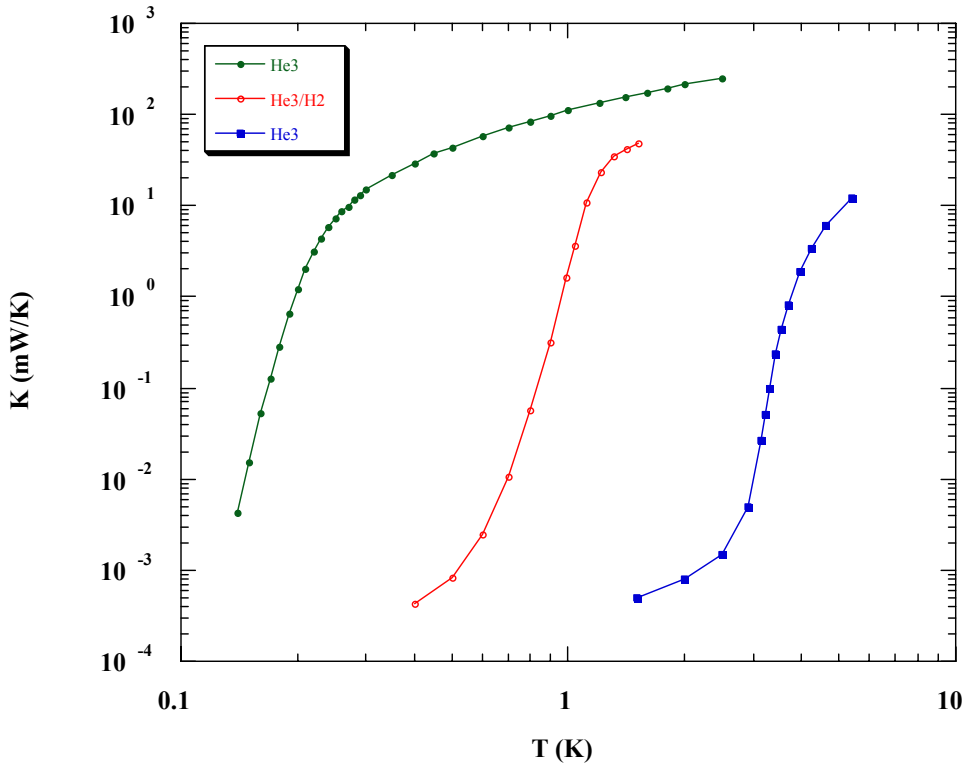




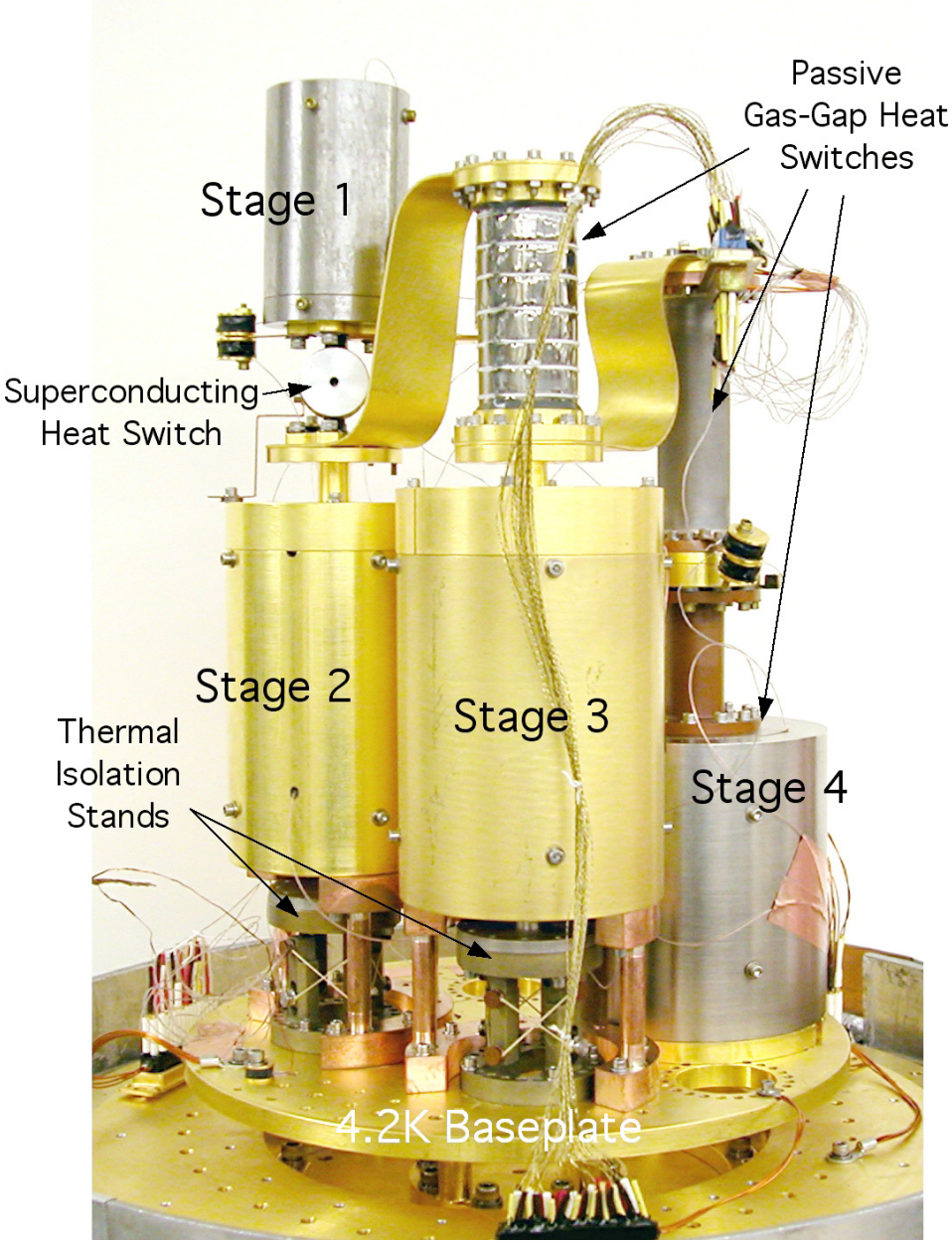
PGGHS Performance

- ***Transition temperature can be tuned by gas species and amount***
  - ***Gas latent heat: He-3 (~.2 K), He-4 (~.8 K), H_2 (~6 K), Ne (~10 K), ...***
  - ***Gas adsorption***
    - ***Substrates: frozen gases, metals, zeolite, charcoal***

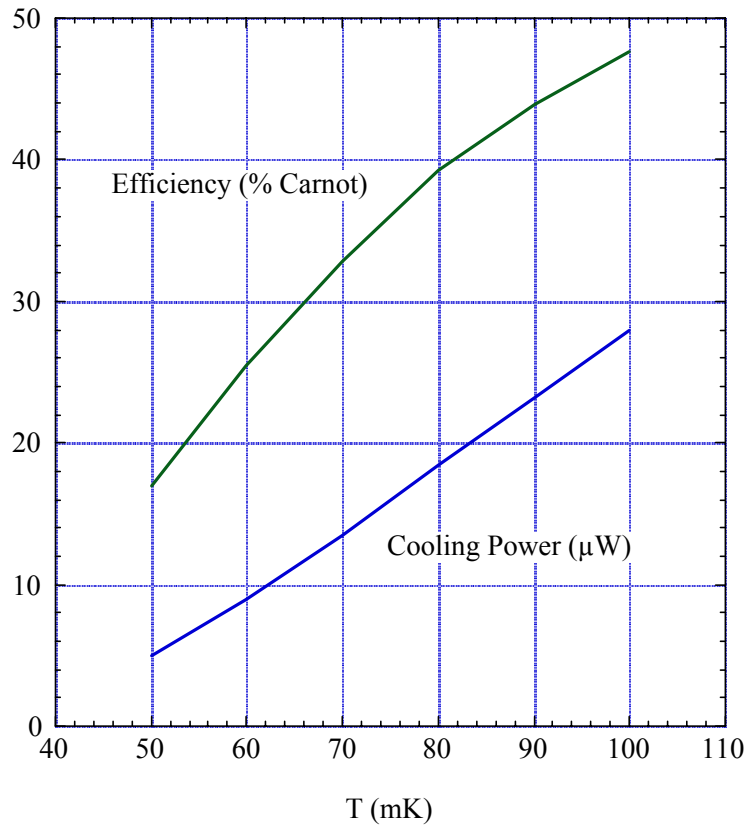
Gas/Substrate	***$T_{ON/OFF}$***
^{3}He/^{3}He	***0.2***
^{3}He/H_2/Sintered SS	***1.0***
^{3}He/Sintered SS	***4.0***
H_2/H_2	***5.2***
Ne/Ne	***11***
^{3}He/Charcoal	***13***



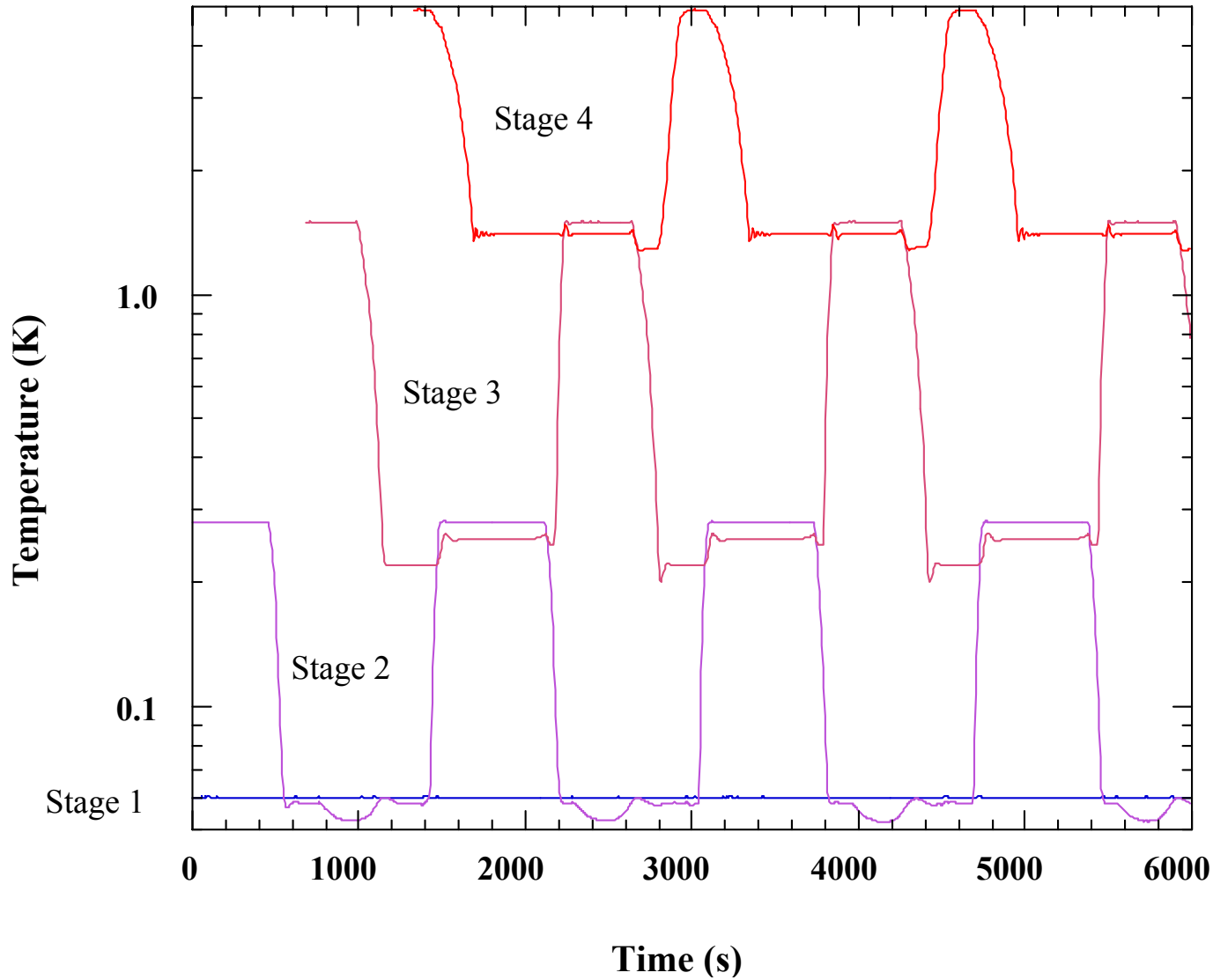
Prototype 4-Stage CADR



- ***4.2 K heat sink***
- ***Total mass of 7.7 kg***
- ***Magnets are fully shielded***
- ***Operation is fully automated***

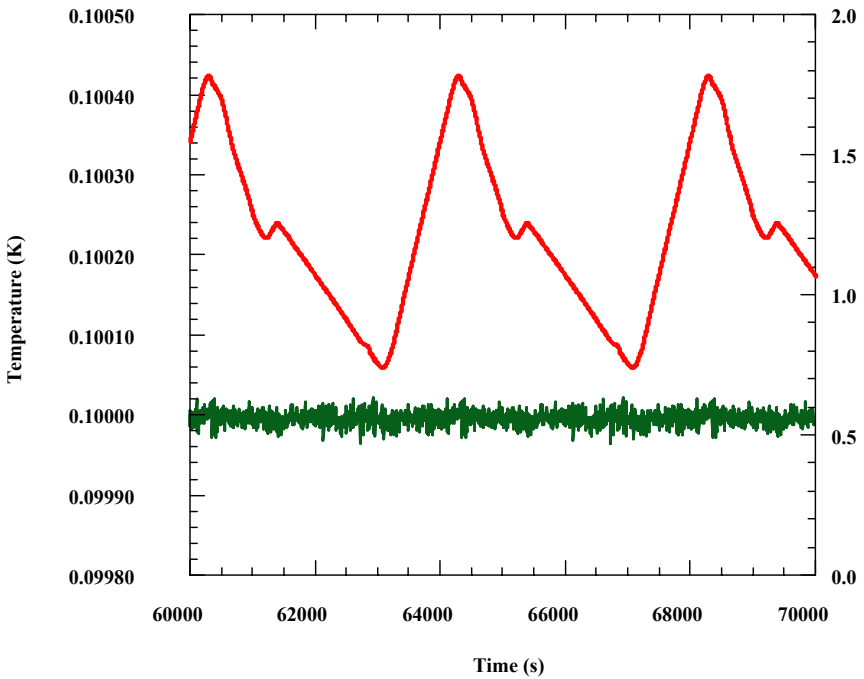


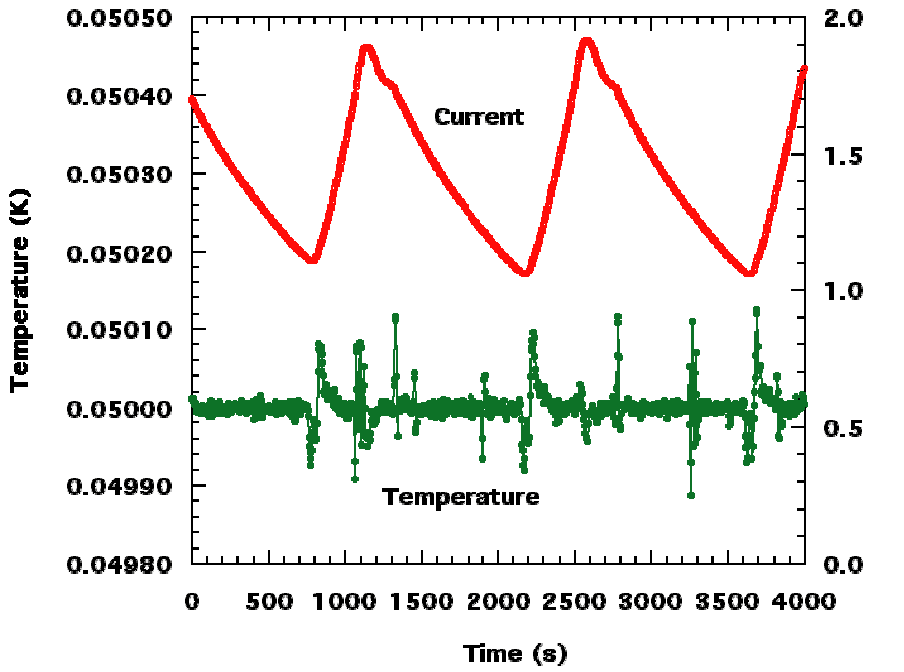
4-Stage Cycling



Temperature Stability

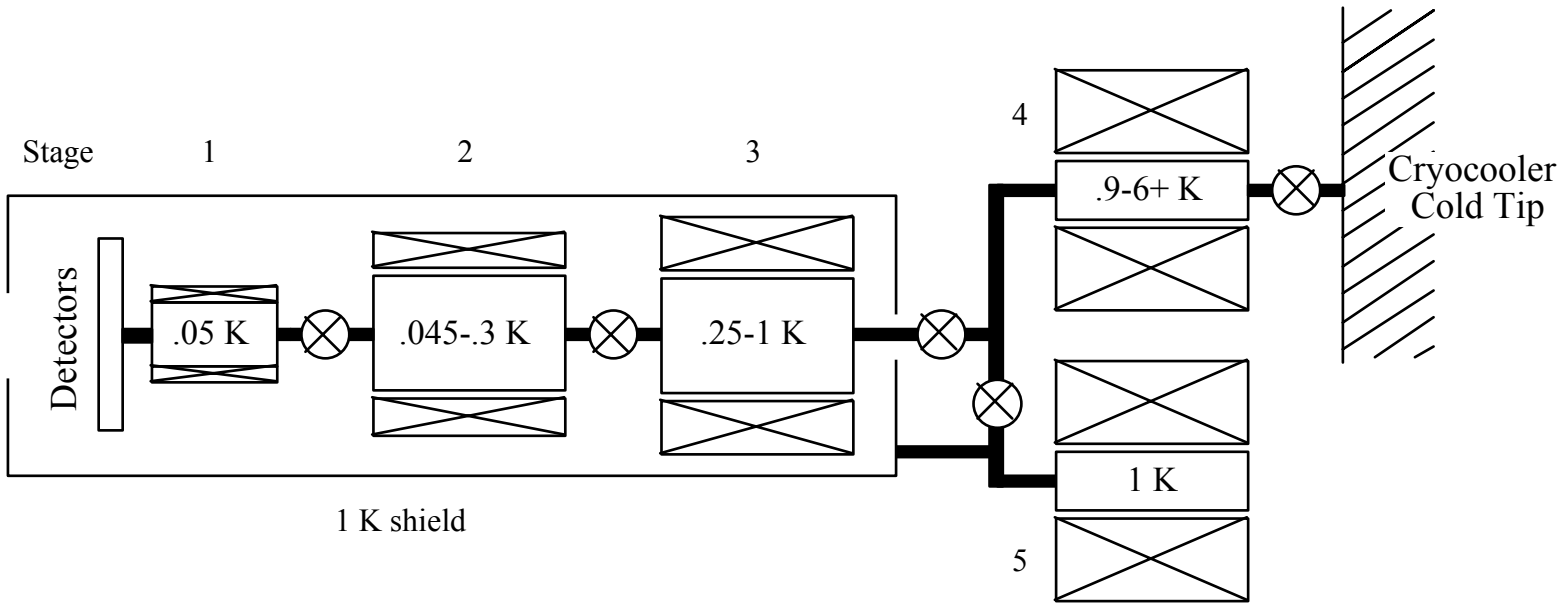
- *Temperature stability at 100 mK is 5-6 μK rms (electronics noise)*
- *Less stable at lower temperature*
  - *Transients as large as 100 μK*





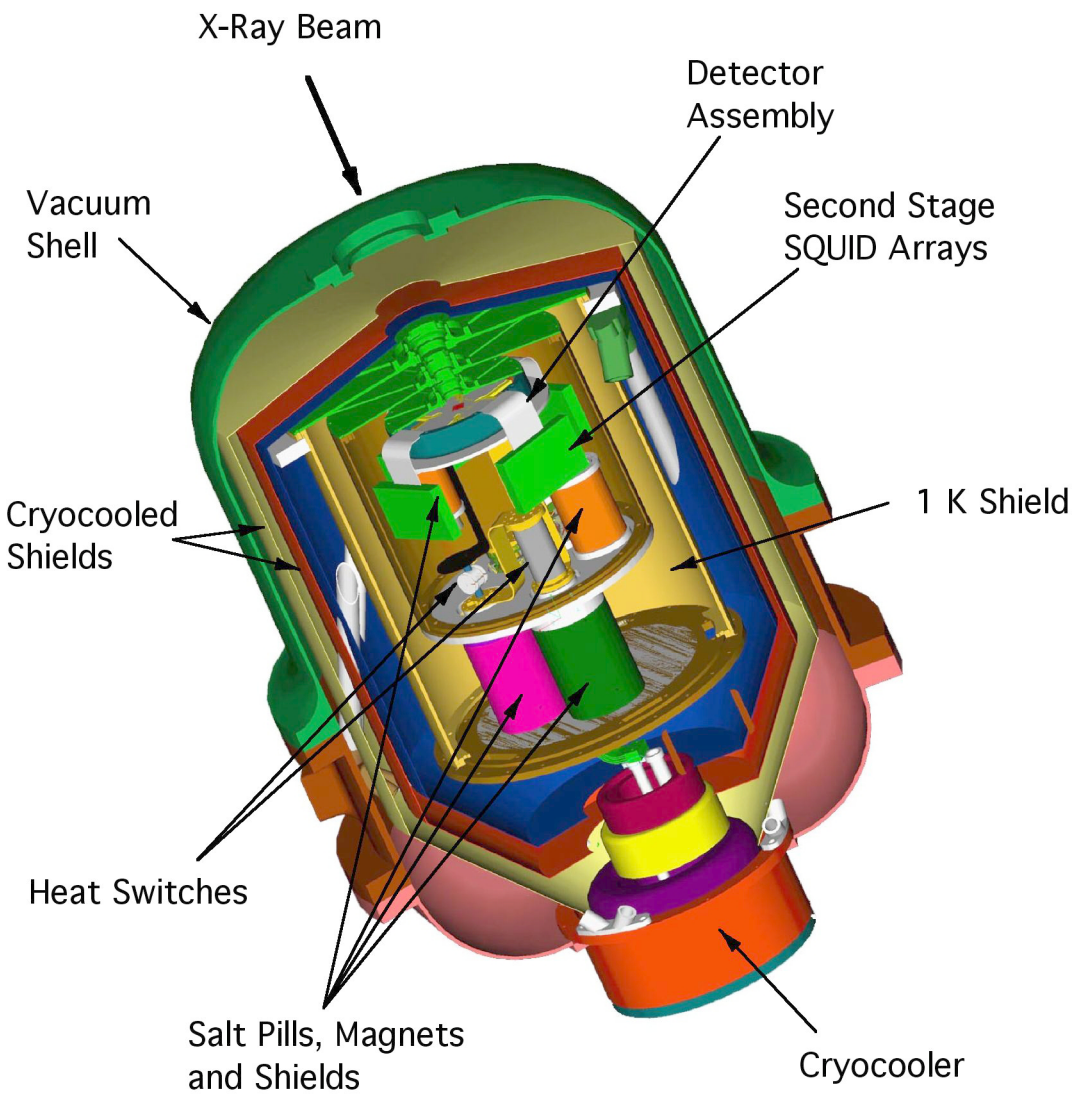
CADR Configuration for Constellation-X

- ***Basic 4-stage CADR for 0.05 to 6 K operation***
- ***Additional stage cools SQUID amplifiers and 1 K shield***



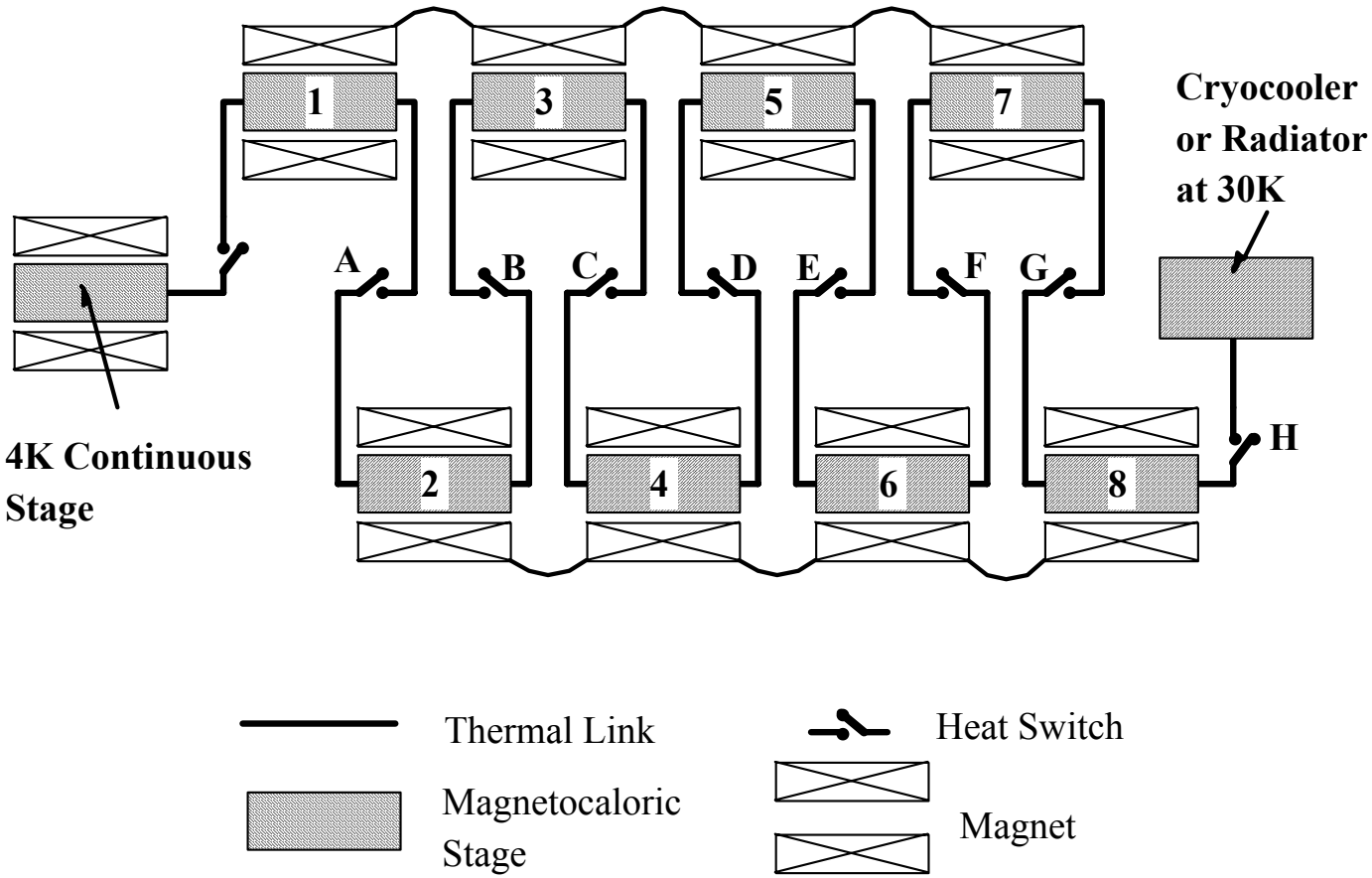
Constellation-X Cryogenic System Layout

- ***X-Ray Microcalorimeter Spectrometer (XMS) Detector assembly***
  - ***32 x 32 TES Detector arrays and first stage SQUID amplifiers at 50 mK***
  - ***Second stage SQUID array amplifiers at 1 K***
- ***Continuous ADR (CADR)***
  - ***~10 kg***
- ***Cryocooler***
  - ***200 mW at 18 K***
  - ***20 mW at 6 K***
    - ***Goal of 4 K operation***

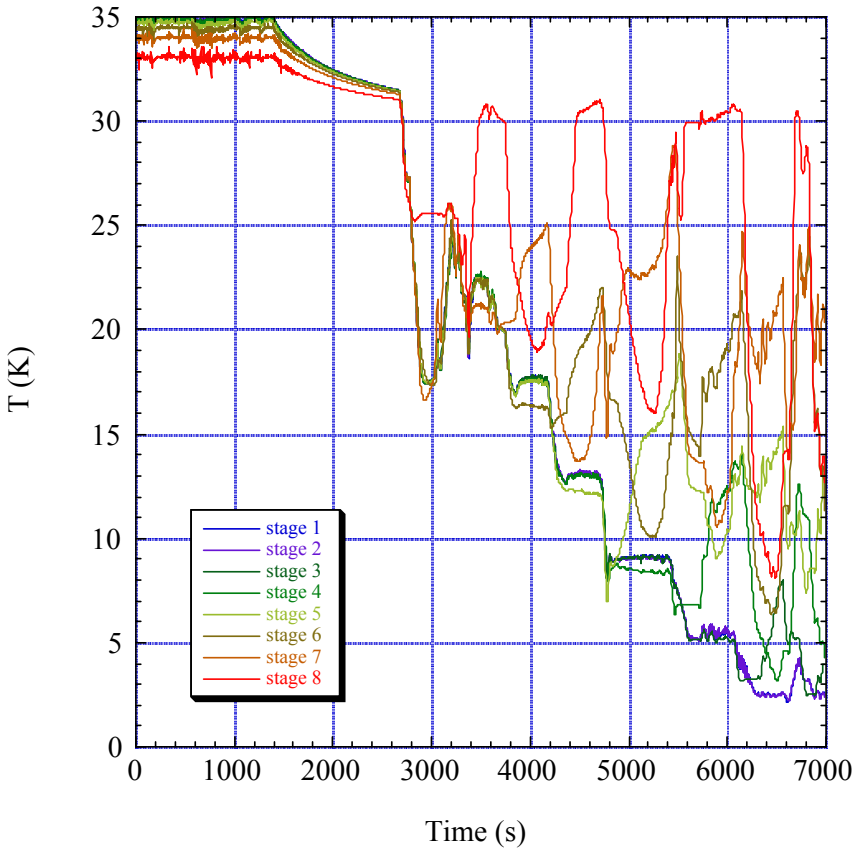


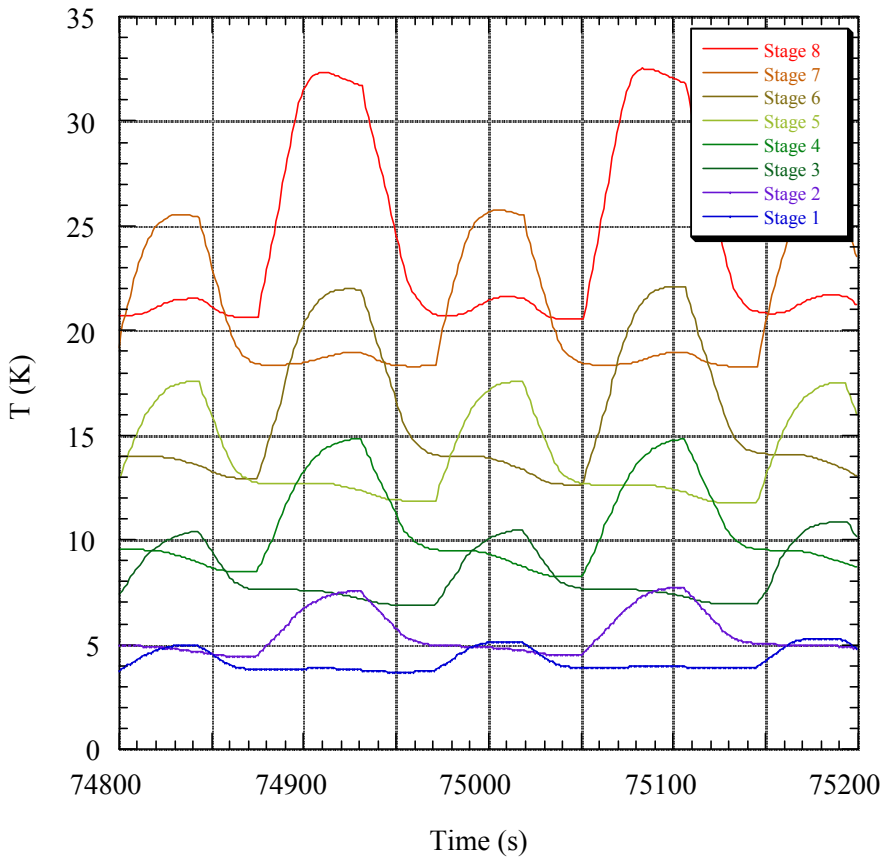
4-30K ADR Configuration

- ***Optimal system uses 8 stages to span 4-30 K***
  - ***Two banks of magnets synchronously driving 4 stages each***
- ***Stages connected by passive gas-gap heat switches***



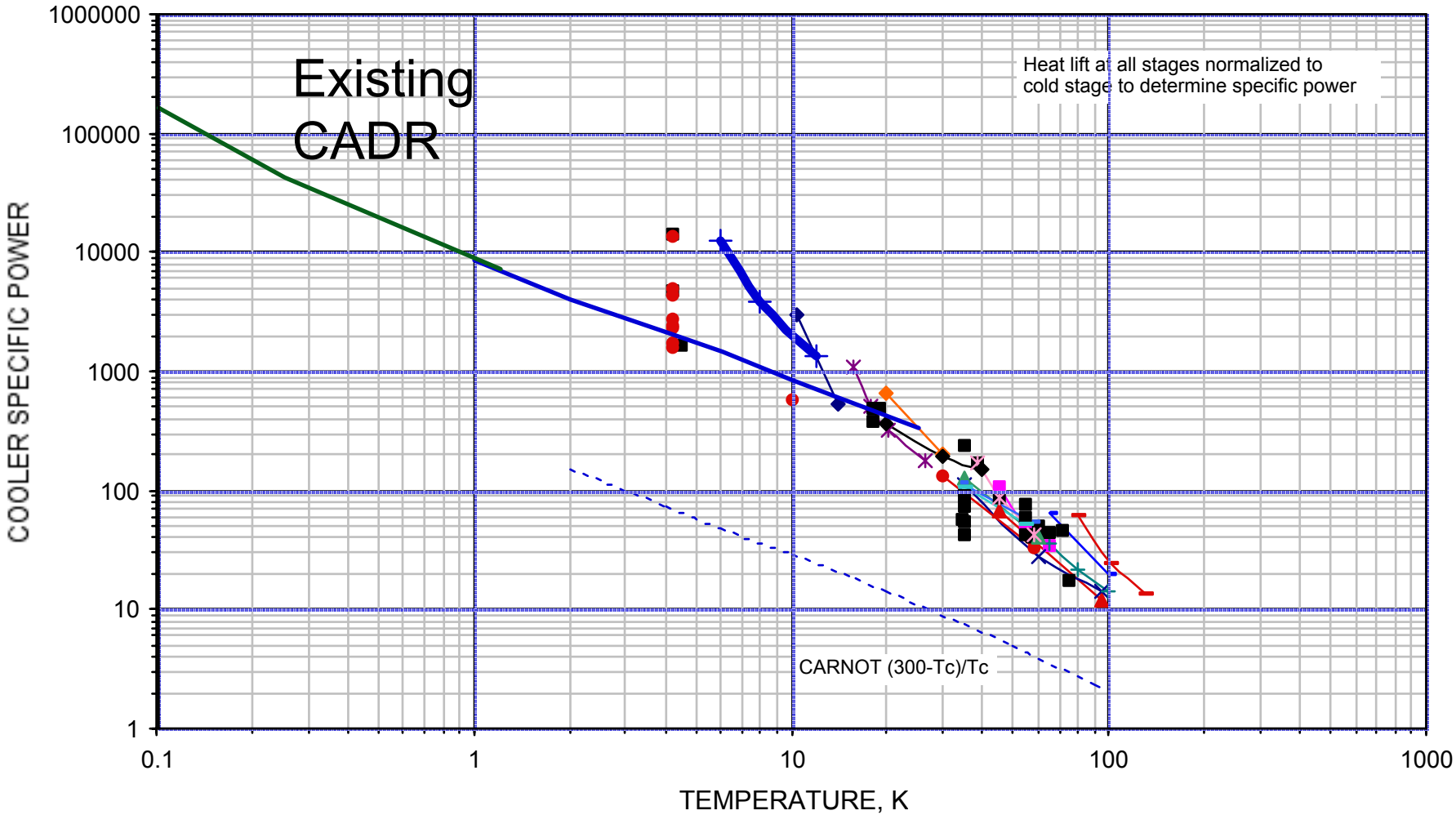
Cooldown and Cycling





- ***Model run for cooling powers up to 10 mW***
- ***Efficiency ~35% (of Carnot)***

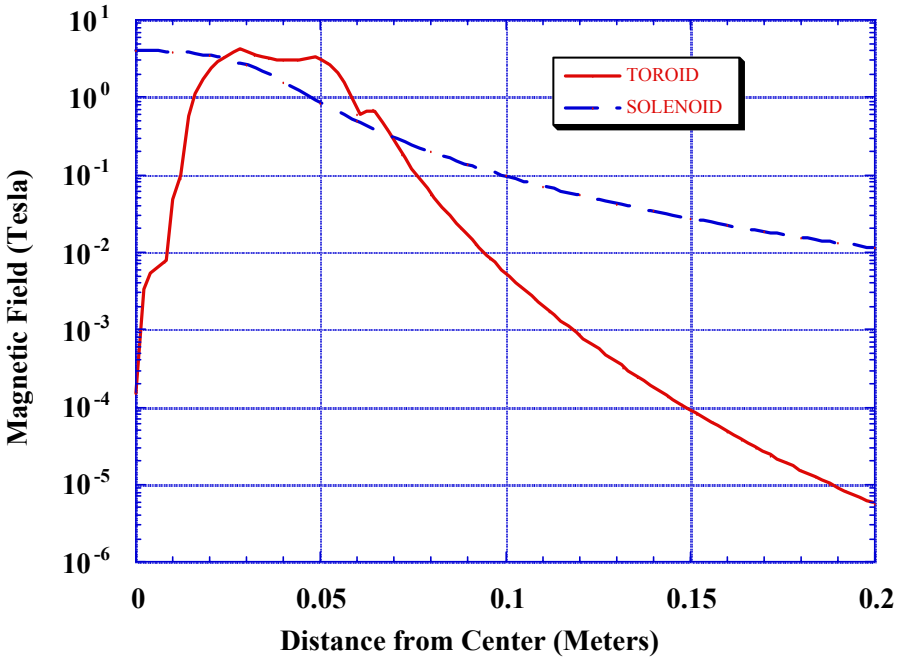
Cooler Comparison

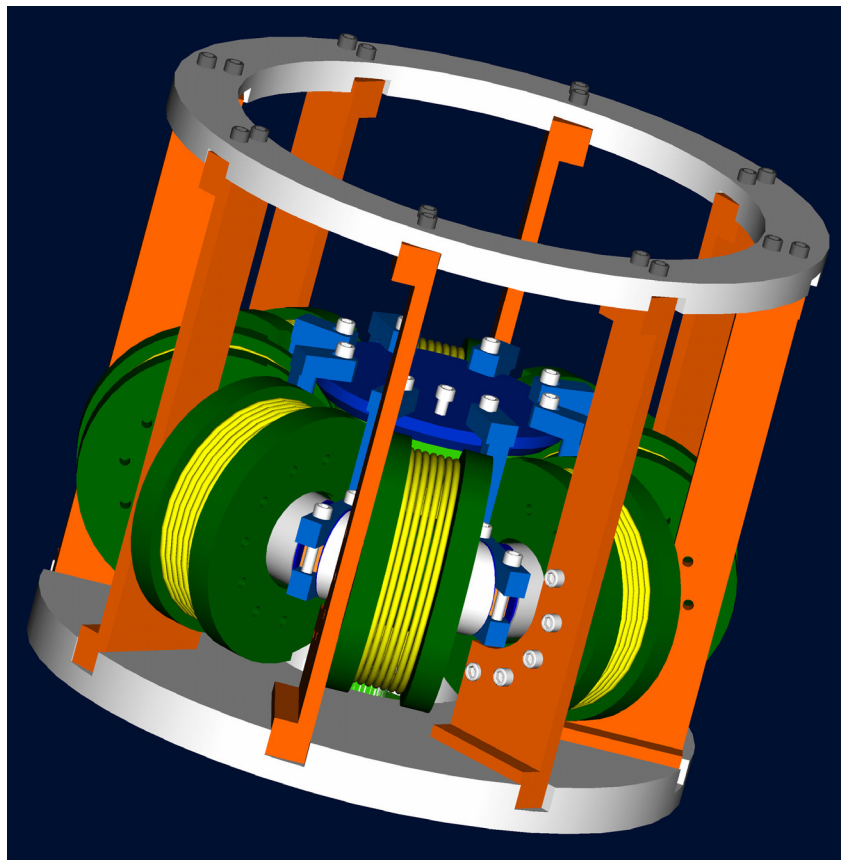


- ***Courtesy of Dean Johnson/JPL***

Toroidal Configuration

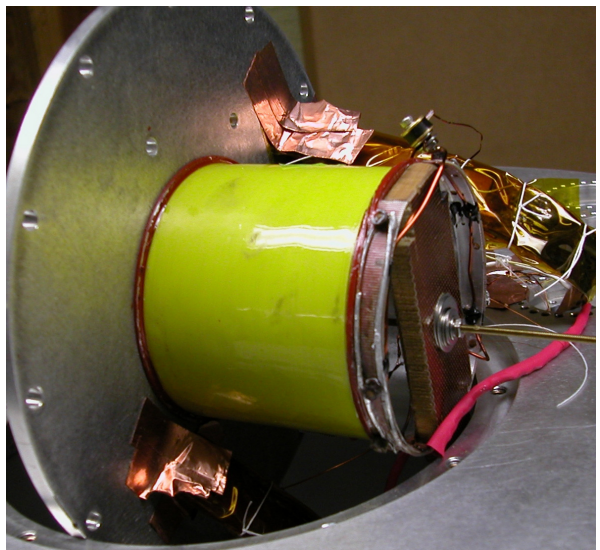
- ***Magnetically self-shielding***
- ***Low mass per cooling power***





Technology Development

- ***Magnets operate at heat sink temperature***
  - ***Operation above 5-6 K operation requires shift from NbTi***
  - ***Possibilities include Nb_3Sn, MgB_2, HTS materials***
    - ***Lead conduction dominates thermal design -> low current***
      - ↗ ***Minimize current and number of magnets***
    - ***Nb_3Sn and HTS difficult to fabricate in small cross-section***
- ***SBIR with Superconducting Solutions, Inc. to develop 3-4 T magnets working at 12+ K using Nb_3Sn***
  - ***Uses 0.2 mm wire in "react and wind" technique***



Summary

- ***ADRs are very versatile***
  - ***Wide temperature range: below 50 mK to above 30 K***
  - ***ADRs are ideal for space use***
  - ***High efficiency compared to other coolers***
- ***Multi-stage architecture***
  - ***Increases performance***
    - ***Lower mass, higher cooling power***
    - ***Lower operating temperature and higher sink temperature***
  - ***Allows cooling stages to be distributed***
- ***Combined high and low temperature systems will provide cooling solution for detectors and telescope***
- ***Presently working to implement a 4-10 K version of multi-stage ADR to be coupled with existing 50 mK system***